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Using VR to Improve the Performance of Low-Earth Orbit Space Robot Operations

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ABSTRACT

The operations of current robotics systems in low-earth orbit could benefit from the use of virtual reality (VR) systems to improve their performance. This paper presents an example of the type of contribution such a system could provide to assist the space robot operators in their operations, by using the increased situational awareness and the ease of use associated with VR systems.

INTRODUCTION

APART FROM THE PAST ROTEX and ETS-7 experiments,[1,2] the operations of low-earth orbit (LEO) space robots are currently limited to the use of the Shuttle Remote Manipulator System (SRMS), and the Space Station Remote Manipulator System (SSRMS).

The SRMS, as its name implies, is installed in the cargo bay of the space shuttle, while the SSRMS is installed on the International Space Station (ISS). Those systems are illustrated in Figure 1.

These two robotics systems are non-autonomous and thus are controlled and supervised by human operators in a human-in-the-loop way, the simplest form of remote control.[3] In both cases the direct views on the worksite of the robots are seldom and therefore, the operators rely almost uniquely on camera views during the operations.

It is important to understand that the visual cues represent the only source of information available to the operators to achieve safe and efficient work. Given this constraint and since it is sometimes impossible to get a good view of specific parts of the worksite, the assistance of other astronauts is often required to assist the operators in their tasks, especially when large objects are manipulated in constrained spaces. In those cases, the assisting astronauts becomes the "eyes" of the operator by taking a "space walk" and going directly on the worksite.[4,5]

These workarounds allow the operator to get a good direct or indirect view of the robot worksite, in order to safely complete the tasks.

Once the assembly of the ISS completed, there will be fourteen cameras installed on it at fixed locations. Each of those cameras is mounted on a pan/tilt unit (PTU) to control their orientation. In addition to that, four cameras are mounted on the SSRMS, one fixed at each end and two others mounted on the arm near the elbow, on PTUs.

The operation of the SRMS and SSRMS constantly alternates between camera selection/control, and robot control, until the task is completed.

The cameras are currently selected and controlled from a display and control panel made of different physical controls such as buttons and switches. The camera control is done by adjusting their different parameters such as pan/tilt/speed/zoom/focus/iris.

On the other hand, the control of the robots is done with the use of two 3-degree-of-freedom hand controllers, as well as a standard graphical user interface. On the ISS, all those interfaces are combined in a control station called the robotic workstation (RWS), shown in Figure 2.

The current workstation is fully functional but requires the operator to remember the location of

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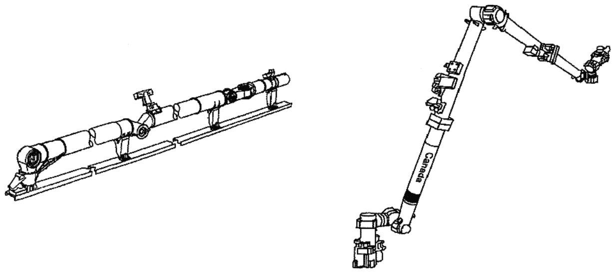

FIG. 1. SRMS (left) and SSRMS (right).

each camera in order to choose the good ones when comes the time to operate the robot. The building of such a cognitive model (mental map) of the system requires a lot of training for the operators and is prone to errors.

The training of both the SRMS and the SSRMS is done on simulators. The training for the SRMS is done by the NASA at the Johnson Space Center. For the SSRMS, the training is done by the Canadian Space Agency at the John H. Chapman Space Center on a simulator called MOTS (MSS Operations and Training System).[6]

The camera selection and control is a crucial part of the robotics system operation and typically, most of the time required to accomplish a task is spent for the selection and control of the cameras in order to get a good view of the worksite. The remaining time is used for the control of the robot.

The performance and safety of space robot operations are of prime importance,[7] and this paper describes a VR-based proof-of-concept human-machine interface that makes use of direct manipulation, and the combination of both the global and local views of the worksite, in order to simplify the operations.

The use of those techniques could eventually reduce the training time required by the operators. We also think that it has the potential to significantly reduce the task completion time.

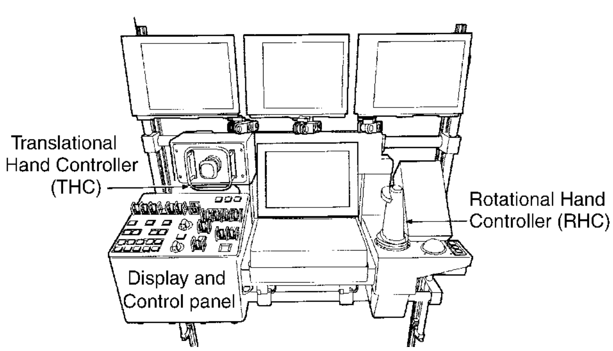

FIG. 2. The ISS Robotic Workstation.

THEORETICAL FOUNDATIONS

The proof-of-concept VR system described here, called COSMOS (Control of Operations in Space and Monitoring of Orbital Systems) is based on VR technologies and its design is based on the recommendations of a task analysis of the operation of low-earth-orbit robots.[4]

This task analysis showed that safety is the most important factor in space and that since direct viewing of the worksite is limited, most of the time, the only way to provide the operator with a view of the worksite is through the use of video cameras.

Since the cameras are located on the ISS itself, all the views provided by them are local in essence and there is no way to obtain a global view of the structure.

This is where VR can help, by providing, through a model of it, a global view of the ISS. This model can then be augmented with additional information and can be observed from any point of view.

This latest feature alone, which is specific to VR systems, makes it useful to increase the situational awareness (SA) of the operators by providing them both a global view of the ISS and a local view of the worksite.

This scenario compares well to the current situation where only local views are available to the operators.

The possibility to add information to the VR scene also can improve the overall productivity by allowing a fast an easy selection and control of the cameras located on the ISS in a way that requires almost no training.

SYSTEM DESCRIPTION

COSMOS is mainly composed of a 3D graphical model of the ISS (based on the planned complete structure) that orbits around a 3D model of the earth. A global view of the system is shown in Figure 3.

COSMOS is currently controlled by a standard computer keyboard and mouse, with two joysticks used for both navigating around the ISS and to control the SSRMS when in robot control mode.

When the operator needs to select a camera view of the worksite, it can easily display the location, orientation and field-of-view of all the cameras, simply by pushing a button.

The display of this information is accomplished by augmenting the VR scene with a pictorial description of the cameras field-of-views in the form of semi-transparent viewing volumes or frustums

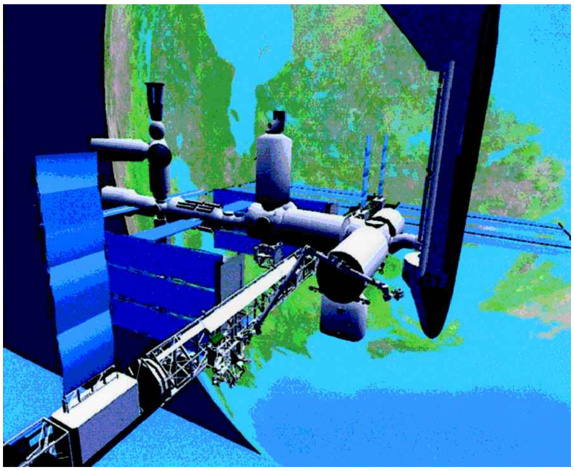

FIG. 3. COSMOS overview.

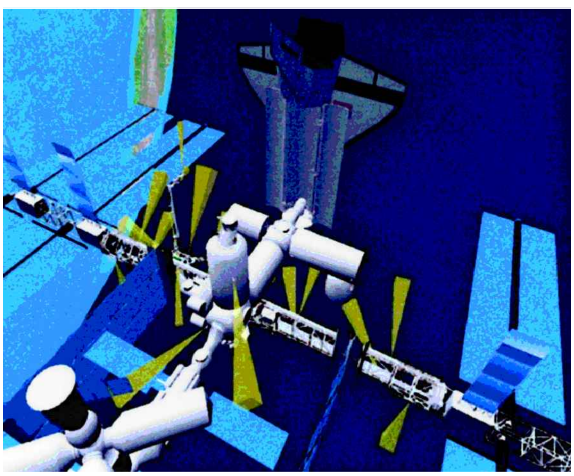

FIG. 4. Camera's view.

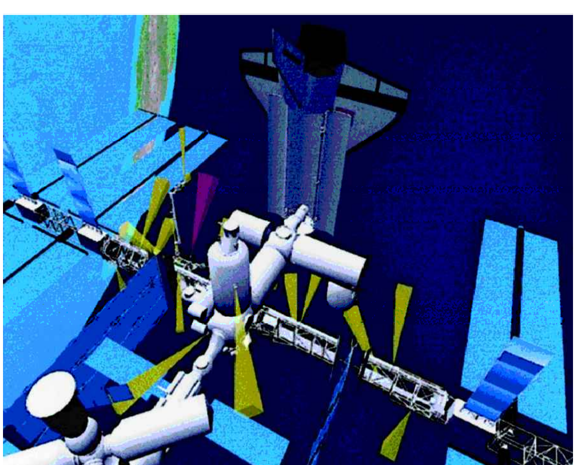

FIG. 5. Visual feedback indicating the selected camera (in red).

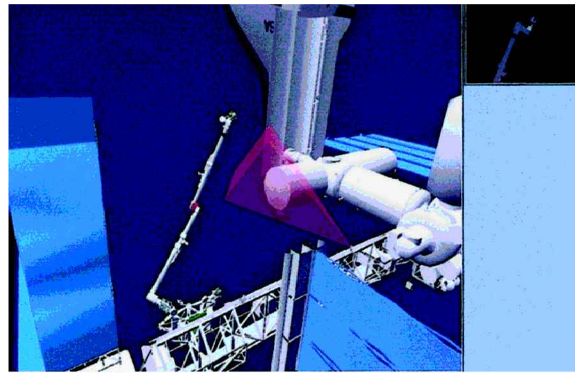

FIG. 6. Selected camera view in a separate window.

(truncated square pyramids) originating from each camera location on the ISS (Fig. 4).

As a result, the operator can easily spot the camera that will give the best view of the desired worksite and select it directly, simply by pointing and clicking on it.

The system confirms the selection of a particular camera view through visual feedback, by changing the color of the selected frustum (Fig. 5).

Also, COSMOS can provide simultaneously the global ISS view and the local worksite view by displaying the particular camera view in a separate window (Fig. 6).

The direct manipulation of the system eliminates the need to remember the location of each camera as well as their associated number. This technique alone has the potential to significantly reduce the operator's training time and the errors associated with the selection of the inappropriate camera views. As a result this could positively impact the overall performance of the low-earth orbit space robot operations.

DISCUSSION

The use of direct manipulation and the fact of being able to see simultaneously a camera location, orientation and field-of-view is a great advantage for the operation of the robots as compared to the current situation. This eliminates the need to remember their location or their number, therefore reducing the training time.

In addition to that, the instantaneous visual feedback associated with the direct manipulation interface eases significantly the selection and control of the cameras.

Moreover, the interactive 3D nature of VR is critical here to illustrate the camera poses, since it is not always possible to show all of them from a single point of view. In fact, when the operator wants to view a particular part of the ISS, the VR system allows to navigate around it and thus change the viewpoint until the area of interest (and the nearby cameras) are visible.

Finally, by having simultaneously access to both the global view of the ISS and the local view of a selected camera, the situational awareness[8] of the operator is significantly increased.

Of course, before the implementation of such a VR interface on the ISS becomes a reality, some issues need to be addressed, one of them being the availability of radiation-hardened computers that are powerful enough to run VR simulations.[9]

Future research could attempt to measure the real performance gains associated with such an interface by running it through real scenarios and comparing the results with those obtained by using the conventional interface. Also, new advanced control modes of the space robots could be explored with the help of a VR system, although more precise models of the ISS could be necessary in this case, something that could be possible with the help of advanced sensing system.[10]

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